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MOLT PATTERN AND DURATION IN A FEMALE NORTHERN GOSHAWK (*Accipiter gentilis*)

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Abstract.—The successive molt patterns (1983–1989) of the major flight feathers (alulas, primaries, secondaries and tail) were studied in a wild bred, captive female German goshawk (*Accipiter gentilis*). Where possible, the date that each feather was shed was recorded, and the rachis length and thickness measured.

The observed variation in the total number of feathers molted each year was due to annual differences in the number of tail and secondary feathers shed. With the exception of 1985, all alulas and primary feathers were replaced annually. The pattern of secondary and tail feather loss in any one year was largely dependent on the molt pattern of the previous year. Although the duration of the overall molt decreased from a maximum of 141 days in 1984 to a minimum of 98 days in 1988, the onset of each molt remained relatively constant between days 134 and 145. The length of 2nd and subsequent primaries was greater than that of the first primaries grown in the nest. A significant thickening of the rachis in some primaries was also found, indicating an increase in feather strength between juvenile and subsequent feathers.

Patrones y duración del cambio de las plumas en un Gavilán Azor hembra (*Accipter gentilis*)

Extracto.—Los patrones del cambio sucesivo (1983–1989) de las plumas necesarias para vuelos mayores (bastardas, primarias, secundarias, y de cola) han sido estudiadas en un Gavilán Azor (*Accipiter gentilis*) hembra, cautiva pero silvestremente incubada y criada. En lo posible, se ha registrado la fecha de la caída de cada pluma, así como se han medido el largo y grosor del cañón. La variación observada en el número total de plumas cambiadas cada año se debió a las diferencias en el número de plumas de cola y secundarias caídas anualmente. Con la excepción de 1985, todas las plumas bastardas y las primarias fueron reemplazadas anualmente. El patrón de caída de las plumas secundarias y de cola en un año, dependió mayormente del patrón de cambio del año anterior. Aunque la duración de la muda total de plumas decreció desde un máximo de 141 días en 1984 a un mínimo de 98 días en 1988, el comienzo de cada muda permaneció relativamente constante entre los 134 y los 145 días del año, contando desde enero. El largo de las segundas y subsecuentes plumas primarias fue mayor que el de las primeras primarias crecidas en el nido. Se encontró un aumento significativo del grosor del cañón en algunas plumas primarias, lo que indica un aumento en el vigor de las plumas correspondiente con la edad del ave.

[Traducción de Eudoxio Paredes-Ruiz]

The goshawk has recently been identified as one of a relatively small number of species in which the lead (Pb) and cadmium (Cd) contamination of certain well defined feathers can be measured and used as an indicator of environmental contamination by heavy metals (Dietrich and Ellenberg 1986). It is therefore important to know when or how frequently certain feathers are molted so that the period of contamination can be determined.

Similarly, radiotelemetry is being used, increasingly, in the study of wild raptors, including goshawks, and in these studies the radios are often attached to one or two tail feathers (Kenward 1978). In order to maximize the amount of data obtained from each radio-tagged bird it is important to attach the transmitters to those feathers which are likely to remain unmolted the longest. The need to understand molt patterns is therefore clear.

The first seven annual molt patterns of a wild bred, captive female German goshawk are described in this paper. The bird was taken as a juvenile in the autumn of the year it hatched (1982) and therefore the successive molts cover the change from juvenile to full adult plumage. The first feathers, grown in the nest, did not start to be replaced until the spring of the following year (1983). I investigated the loss and replacement of the main flight feathers (alulas, primaries, secondaries and tail). This long-term study of an individual captive bird kept under conditions of natural light, temperature and excess

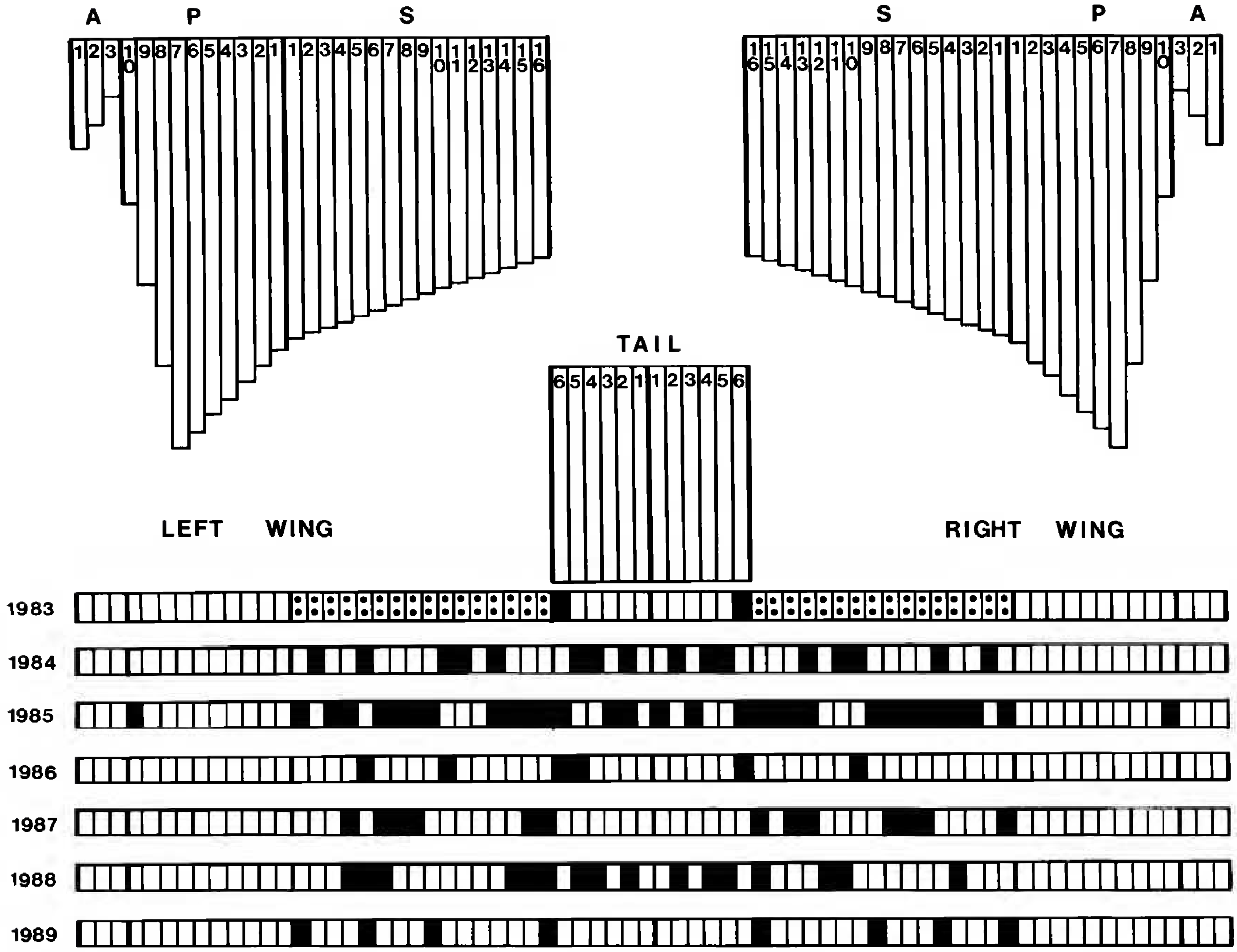

Figure 1. Diagrammatic representation of the main flight feathers in the Goshawk. A = alulas, P = primaries, S = secondaries. The bar codes show which feathers were molted (open cells) or retained (solid cells) each year between 1983 and 1989. The stippled cells represent those feathers for which no molt data were obtained.

food also enabled the changes in molt pattern between years, and the interdependent effects of one molt on the next, to be investigated. Between each molt (October–March) the bird was regularly flown at quarry. It may therefore be considered as a baseline study of a bird, under minimal stress during molt, to which studies of wild birds under many different stresses (food shortage, breeding, weather etc.) can be compared. Although molt data of this type are much more difficult to obtain from studies of wild birds, some limited success was achieved by Brüll (1984) studying wild German goshawks between 1950 and 1959. Unfortunately his data are incomplete. In contrast the molt data obtained in this study are complete for each of the four main flight feather types for either 6 or 7 years and should be viewed as being complementary to those of Brüll (1984).

METHODS

With the exception of the first year of the study (1983) the date on which each alula, primary, secondary and tail feather was molted was recorded. In 1983 only the primary and tail feathers were recovered and the date on which each was molted was not recorded.

The thickness of the rachis of each feather was measured to an accuracy of 0.01 mm using vernier calipers. With the blade of the feather in the horizontal plane, the thickness of the rachis was taken in the vertical plane at a point 5 mm proximal to the point where the feather barbs attach to the rachis. Flattened rachis length was taken as a measure of feather length and was recorded to an accuracy of 1.0 mm. It was only possible to measure those feathers that were found intact.

All the feathers were numbered in the following way

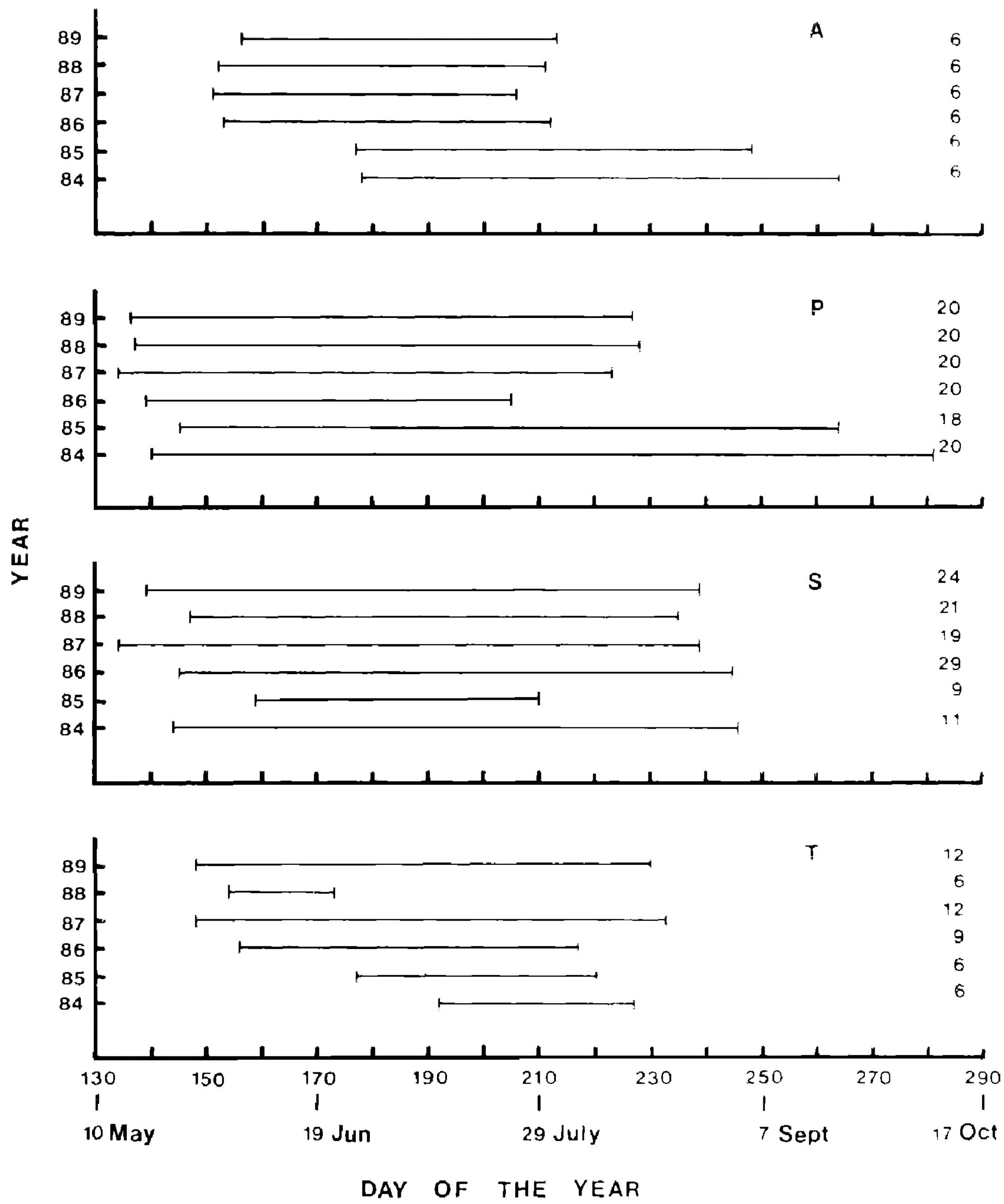

Figure 2. Start and duration of the molt in each of the main flight feather types in the Goshawk for each year from 1983 to 1989. A = alulas, P = primaries, S = secondaries, T = tail. The figures show the number of each feather type molted each year.

The alulas were numbered from the outermost inwards (1–3); the primaries from the innermost outwards (1–10); the secondaries from the outermost inwards (1–16) and the tail from the innermost outwards (1–6). The date on which a particular feather was molted was recorded as the nth day of the year with January 1st being day 1. This convention overcame the potential problem of the extra day during leap years (1984, 1988).

The data were analysed using either Student's t-test or linear regression analysis.

RESULTS

A summary showing which feathers were molted during each of the years for the period from 1983–1989 is given in Fig. 1. Similarly the overall duration of each molt for each feather type, and the number of feathers shed, are shown in Fig. 2. Each of the four feather types collected will be dealt with separately.

Alulas. All three alulas on both wings were molted every year, and in sequence, beginning with feather 3 and ending with feather 1. Although the interval between equivalent feathers on each wing being molted ranged from 0–20 days there was an overall reduction in the length of the interval between successive feathers being shed between 1984 and 1986 (Table 1). Between 1986 and 1989 this interval remained relatively constant.

The starting date of the alula molt changed noticeably between 1985 and 1986. In 1984 and 1985 the molt began on days 178 and 177, respectively, whilst between 1986 and 1989 the molt started between days 151 and 156, approximately 24 days earlier. Concurrent with this earlier start there was a reduction in the overall time taken for all six feathers to be shed from between 86 and 71 days in 1984

Table 1. Mean number of days taken to molt each feather each year (1984–89) in a female goshawk.

YEAR	ALULA	PRIMARY	SEC-OND-ARY	TAIL	OVER-ALL
1984	14.3	14.1	9.3	5.8	2.6
1985	11.8	13.2	11.3	7.2	3.1
1986	9.8	7.3 (6.6)[a]	6.9	6.8	1.7
1987	9.2	8.9	11.0	7.1	1.8
1988	9.8	9.1	8.4	3.2	1.9
1989	9.5	9.1	8.3	6.8	1.7
(1984–85)					
Mean	13.1	13.7	10.3	6.5	2.9
SD	1.8	0.6	1.4	1.0	0.4
N	2	2	2	2	2
(1986–89)					
Mean	9.6	8.6	8.7	6.0	1.8
SD	0.3	0.9	1.7	1.9	0.1
N	4	4	4	4	4

[a] In 1986 primary 10, which was not shed in 1985, was shed out of sequence thus resulting in an artificially low mean (6.6). The corrected mean was calculated excluding the feather 10 pair.

and 1985 to between 55 and 59 days for the period 1986 to 1989 (Fig. 2).

Primaries. All ten primaries on each wing were molted every year except 1985 when primary 10 on each wing was retained (Fig. 3). With the exception of 1986 they were also molted in sequence, starting with feather 1 and ending with feather 10. Although feather 10 was molted out of sequence, between feathers 7 and 8, in 1986 the intervals between the loss of feathers 1 to 9 were not affected. Equivalent primaries on each wing were usually molted on the same day or within 5 days of each other.

Unlike the pattern shown by the alula molt there was no clear change, between 1984 and 1989, in the starting date of the primary molt (days 134–145). There was, however, a significant reduction (t = 7.05, df = 4, $P < 0.01$), from 1985 to 1986, in the interval between the shedding of successive feathers from a mean of 13.7 days in 1984/1985 to 8.6 days between 1986 and 1989 (Table 1) resulting in a large reduction in the overall time taken to complete the primary molt (Fig. 2).

Secondaries. The total number of secondary feathers molted each year was unpredictable and varied considerably from a minimum of 9 in 1985 to a maximum of 29 in 1986 (Fig. 1). The start of the secondary molt was also more variable than that of the alulas or primaries ranging between day 134 in 1987 and day 159 in 1985 (Fig. 2). No significant change was found in the interval between the molting of successive feathers during the course of the study (t = 1.13, df = 4, $P > 0.10$; Table 1). There is some evidence, however, to suggest that feathers retained in a particular year were more likely to be molted the following year than those that were previously molted. In only one year, 1986, was an almost full

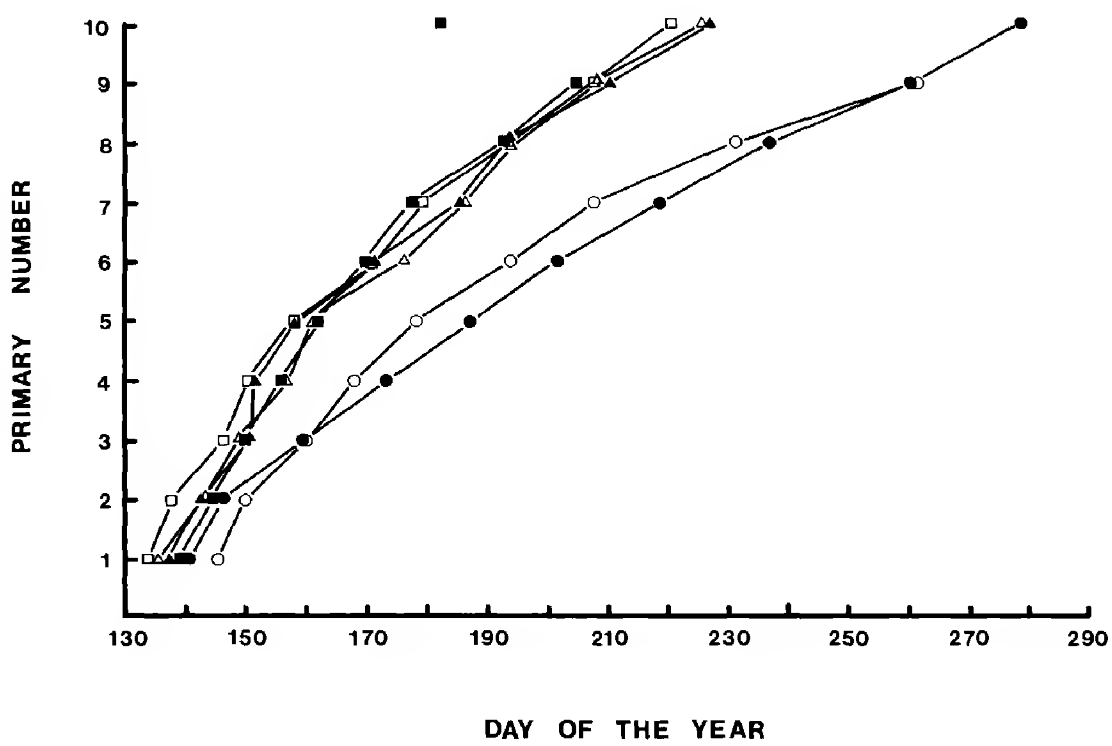

Figure 3. The mean molt date for each pair of primary feathers between 1984 and 1989. ● = 1984, ○ = 1985, ■ = 1986, □ = 1987, ▲ = 1988, △ = 1989. The No. 10 primary, molted out of sequence in 1986, is the primary that was not shed in 1985.

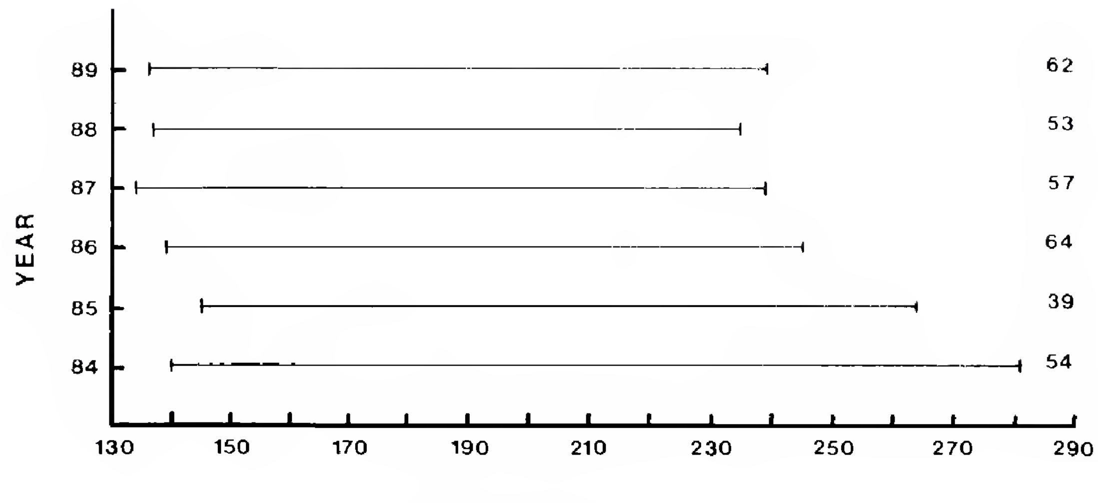

Figure 4. Start and duration of the complete molt for each year between 1984 and 1989. The figures show the total number of feathers molted each year.

complement of secondaries molted and replaced (29/32 feathers).

The sequence in which the feathers were molted varied between years and was, to some extent, also dependent on whether or not a particular feather had been molted the previous year. However, by scoring each molted feather, each year, according to when it was molted and by combining the scores for equivalent feathers on each wing a pattern was found. Overall, the secondary molt followed the sequence: feather 6, 15, 5, 3, 11, 10, 2, 7/14, 12, 13, 9, 8, 4, 1, 16. This pattern suggested the presence of four molt centers on each wing at feathers 3, 6, 11 and 15.

Tail. As with the secondaries, the total number of feathers molted each year was largely unpredictable ranging between 6 and the full complement of 12. There was, however, a tendency for feathers that had not been shed in one year to be shed the following year (e.g., 1984/85; Fig. 1).

The starting date of the tail molt got progressively earlier between 1984 (day 192) and 1987 (day 148), and then stabilized at between days 148 and 154 over the last three years with the biggest difference occurring between 1985 and 1986 (Fig. 2).

The sequence in which the feathers were molted varied between years and was dependent on whether or not a particular feather had been shed the previous year. However, by using the method already explained for secondaries the overall molt pattern for either side of the tail followed the sequence: feather 5, 1, 2, 6, 3, 4. Exceptions to this usually started with the sequence: feather 1, 6, 3.

Overall Timing and Duration of Molt. The total number of major flight feathers molted each year varied between 39 in 1985 and 64 in 1986, the full complement being 70. Of these the number of alulas and primaries molted annually remained almost constant whilst the variation in the number of secondaries and tail feathers that were molted accounted for the annual differences in the total number of feathers molted.

The start of the annual molt occurred between days 134 and 145. The apparent trend towards an earlier start date with increasing age was not significant ($r^2 = 0.47$, $N = 6$, $P > 0.05$). The time taken to complete the annual molt (Fig. 4) decreased progressively from 141 days in 1984 (54 feathers) to a minimum of 98 days in 1988 (53 feathers). The largest difference between the mean time to molt each feather occurred between 1985 (3.1 days) and 1986 (1.7 days).

Rachis Length and Thickness. Because the 1983 alulas and secondaries, though molted, were not collected it was impossible to compare their rachis lengths with those of feathers from subsequent molts. Similarly, though collected, the 1983 tail feathers all had damage to their tips and therefore it was impossible to compare rachis length in these feathers during the change from juvenile to first adult plumage. It was possible, however, to compare rachis lengths and thicknesses for primary feathers from all seven years. Both an increase in rachis length between first and subsequent years (Table 2) and an increase in rachis thickness were found (Table 3). The thickening of the rachis between 1983 and 1984 did not occur in all the primaries equally, being most noticeable in feathers 1–5.

An analysis of tail feather rachis thickness showed that a significant thickening was only detected in

Table 2. Comparison of mean feather/rachis length (mm) between 1st and subsequent molts for equivalent primaries on the left and right wing of a female goshawk.

FEATHER TYPE		FEATHER NUMBER 1	2	3	4	5	6	7	8	9	10
Primary (1st)	Mean	211	214	222	233	239	265	—	240	226	—
	SD	0	1.4	6.4	11.3	—	0	—	0	2.8	—
	N	2	2	2	2	1	2	—	2	2	—
Primary (2nd+)	Mean	214	222	230	245	275	289	—	—	229	159
	SD	1.4	1.2	1.9	2.2	4.7	8.0	—	—	2.9	2.3
	N	11	12	12	12	7[a]	4	—	—	5	9

[a] Primaries 5–10 being both the outermost and including the largest feathers (5–8) were most prone to damage often making it impossible to measure their length.

feathers 3 ($t = 2.27$, df = 10, $P = 0.05$) and 6 ($t = 5.31$, df = 6, $P = 0.002$) between first and subsequent molts.

DISCUSSION

A number of conclusions can be drawn from this study of molting in a captive female goshawk. Although all the alula and primary feathers were replaced during the first molt, some tail and possibly some secondary feathers remained and were not shed until the second molt. With the exception of one year, all the alulas and primaries were replaced every year. Previous studies of wild sparrowhawks in Scotland (Newton and Marquiss 1982) and both wild sparrowhawks and wild goshawks in the Federal Republic of Germany and the Netherlands (Brüll 1984, Opdam and Müskens 1976) have demonstrated similar molt patterns for the primaries but none looked at the smaller alulas. Complete replacement of the secondary and tail feathers did not occur annually. Instead, it was found that in these two feather types the molt pattern in any particular year was determined to some extent by the molt pattern of the previous year.

Table 3. Mean rachis thickness (mm) of 2nd and subsequent feathers compared with that of 1st feathers. Means calculated using the combined data for equivalent feathers from both wings.

FEATHER TYPE		FEATHER NUMBER 1	2	3	4	5	6	7	8	9	10
Alula (1st)	Mean	—	—	—							
Alula (2nd+)	Mean	3.27	2.89	2.37							
	SD	0.07	0.09	0.06							
	N	12	12	12							
Primary (1st)	Mean	3.71	4.04	4.32	4.53	4.81	5.04	4.69	4.47	3.88	3.28
	SD	0.04	0.06	0.08	0.13	0.13	0.06	0.01	0.04	0.06	0.03
	N	2	2	2	2	2	2	2	2	2	2
Primary (2nd+)	Mean	4.40	4.58	4.80	5.03	5.28	5.26	5.00	4.60	4.01	3.40
	SD	0.10	0.09	0.05	0.07	0.11	0.15	0.15	0.13	0.13	0.10
	N	12	12	12	12	12	12	12	12	12	10
Tail (1st)	Mean	4.89	5.06	5.01	5.15	5.16	5.03				
	SD	0.27	0.06	0.01	0.01	0.08	0.04				
	N	2	2	2	2	2	2				
Tail (2nd+)	Mean	4.80	5.02	5.16	5.19	5.18	5.24				
	SD	0.17	0.16	0.09	0.08	0.09	0.05				
	N	10	7	10	8	7	6				

The increases in feather length between juveniles and adults, seen by Opdam and Müskens (1976) in wild goshawks, were also found in this study. Increases in the thickness of the rachis of some primary (feathers 1-5) and tail (feathers 3 & 6) feathers were also detected. This occurred between the juvenile and first adult feathers and suggests an actual strengthening of the feathers rather than proportional growth. The reasons for this are unclear but may be a response to differences in food availability. Food shortage as a chick may well result in reduced feather growth, whereas in captivity feather growth would not have been constrained in this way, resulting in stronger feathers. In addition, and consistent with this hypothesis, is the fact that the feathers of the first plumage are all grown simultaneously whereas feather replacement following a molt is staggered.

The other main changes occurred between the third and fourth molts. The fourth molt of both the alula and tail feathers started earlier and the duration of the alula and primary molts shortened significantly. In contrast to the findings of Newton and Marquiss (1982) for the sparrowhawk, the onset of the molt remained relatively constant during the seven years of the study and may even have occurred a little earlier as the bird aged.

In a comparison between the molt patterns observed in wild German goshawks (1950-1959) by Brüll (1984) and the captive German goshawk in this study two clear differences emerge. First, the start of the primary molt in the wild birds occurred, on average, about 50 days earlier than in the captive bird but proceeded at approximately the same rate (Brüll's data for the end of the primary molt are poor). Second, the interval between successive primaries being shed in the wild birds was initially very short: 2-7 days for primaries 1-4; but then increased to 16 days between primaries 4 and 5. Brüll gives no reliable data for primaries 6-10. No such sudden increase in the molt interval was found in the captive bird. These differences may illustrate both the hormonal control of molting and its known correlation with egg laying (Brüll 1984) which in Germany usually occurs in late March or early April (approx day 90), and the effect of food stress on molting and feather growth. Once the female has eggs, she is dependent on the male for food.

With respect to radio-tagging wild goshawks, the tail feather molt pattern determined in this study suggests 1) that feathers 2/3 or 3/4 should be used for the attachment of transmitters, thus largely supporting Kenward's finding (1978) and 2) that new feathers should be used in preference to old ones since these have the highest chance of remaining unmolted the following year.

This was a study of a single captive goshawk and therefore the data should be interpreted with care, particularly when extrapolating to the wild situation. Nevertheless, the data are relevant for those studying wild goshawks/raptors in that they show both the changes that occur in molt pattern with age and the relationship between successive molt patterns.

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